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AFRL BATTLESPACE VISUALIZATION BRANCH DISPLAY CHARACTERIZATION FACILITY

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FOR THE COMMANDER

//Signed//

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Digital displays will play a critical role in providing a common battlespace picture whether in the aircraft cockpit, command and control facility or carried by ground troops. Advanced display technologies will be key to providing our warfighters with needed information. The purpose of the Display Characterization Facility at WPAFB is to provide quantitative performance data on current and upcoming display technologies and evaluate these technologies for specific Air Force applications. This requires an understanding not only of the specific display technology and its capabilities and limitations but also the capabilities and limitations of the human visual system, the tasks to be performed and characteristics of the environment which may affect the operator-display interaction. To this end, the Display Characterization Laboratory conducts both display hardware measurements and assessments of human performance using the displays under expected environmental conditions. Common display measurements are described along with their implications for operator visual performance.

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AFRL Battlespace Visualization Branch

Display Characterization Facility

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INTRODUCTION

Not long ago, our only choices for cockpit displays were analog dials and gauges and the occasional CRT which was used primarily for imagery display. Today, with many new display technologies currently on-the-shelf and others under development, there are many choices available both for cockpit displays and for ground-based applications. A variety of helmet-mounted and flat panel displays are now available for use in the cockpit. For ground-based applications, large screen displays allow greater amounts of information to be displayed on a single surface and shared among multiple operators.

Digital displays will play a critical role in providing a common battlespace picture whether in the aircraft cockpit, command and control facility or carried by ground troops. Advanced display technologies will be key to providing our warfighters with needed information.

Many new display technologies are now on the market or soon to be matured. These displays offer higher resolution, greater dynamic range of luminance, larger screen sizes, miniaturization for helmet/head–mounted applications, different color gamuts, display flexibility and wireless interfaces. As Air Force information display requirements become more complex, many of these characteristics are expected to lend themselves to Air Force display applications.

The purpose of the Display Characterization Facility at WPAFB is to provide quantitative performance data on current and upcoming display technologies and evaluate these technologies for specific Air Force applications. This requires an understanding not only of the specific display technology and its capabilities and limitations but also the capabilities and limitations of the human visual system, the tasks to be performed and characteristics of the environment which may affect the operator-display interaction. To this end, the Display Characterization Laboratory conducts both display hardware measurements and assessments of human performance using the displays under expected environmental conditions.

The Display Characterization Facility is shown in Figure1. Facility activities include characterization of off-the-shelf displays of all types. In addition, the laboratory is often called upon to evaluate prototype displays which may look promising for Air Force applications. Display luminance/contrast capabilities, color gamut, visibility in various ambient illumination conditions, off axis visibility, reflection and night vision goggle compatibility are just some of the issues

Figure 1. Display Characterization Facility at Air Force Research Laboratory.

which must be addressed. Laboratory personnel also assist Air Force program managers and engineers in creating display specifications for their particular applications.

As new display technologies are developed, procedures for characterization of these new displays must be standardized. Laboratory personnel are working in collaboration with the National Institute of Standards and Technology and the Vehicular Display Metrology Working Group to develop and standardize display characterization procedures.

This paper will describe the display measurements most often performed in our laboratory and discuss why these measurements are important.

MAJOR EQUIPMENT

The laboratory contains state-of-the-art hardware and software for both in-laboratory ad on-site display characterization. Some of the major items of equipment are listed below:

- Instrument Systems IS-320 Spectroradiometer (2)
- Microvision SS-330 Display Analysis System
- Eldim EZ-Contrast Measurement System
- Hoffman LS-65 Calibrated Light Source
- Hoffman LM-33-52 Sunlight Readability Test Set
- Photo Research PR-650 Portable Spectroradiometer
- Rooftop Dome Observatory (Figure 2)

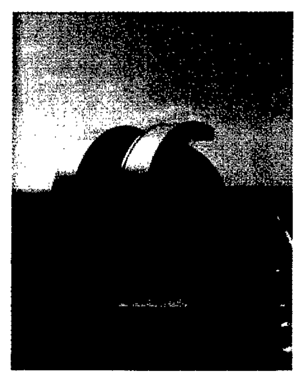

Figure 2. Dome Observatory

COMMON DISPLAY MEASUREMENTS

While the selection of measurements to be performed on any display will depend on where and how the display is intended to be used, there are a number of measurements which are applicable to almost any display. These in include:

- Display Luminance Range and Contrast Ratio
- Gray Scale and Display Gamma
- Display Color Gamut & Color Coordinates
- Shadowing
- Uniformity of color and luminance
- Viewing Angle Effects upon Luminance, Contrast and Color
- Ambient Illumination Effects upon Contrast
- Checkerboard Contrast
- Response Time
- Power Consumption

In addition, there are two other measurements which are often very important for military applications. These are:

- Sunlight Readability
- Night Vision Compatibility

Each of these measurements will be discussed in further detail in the following paragraphs.

Display and measurement equipment set up is critical to any display evaluation. All measurements are conducted in accordance with applicable military standards and the Video Electronics Standards Association (VESA) display measurement standards. The calibration guidelines and set up procedures are set forth in the VESA Flat Panel Display Measurements Standard, Version 2.0 Publication. In house calibration facilities assure that all measurements are traceable to National Institute of Standards and technology (NIST) standards.

Display Luminance Range and Contrast Ratio

Display luminance range and contrast ratio are determined by measuring the luminance of full screen white and full screen black. These two measurements are typically made in the center of the display. The units are typically expressed in candelas per meter squared (cd/m^2). The full screen white measurement requires maximum output from each of the primary display elements, Red, Green and Blue. For a display system with 8 bit color depth the inputs would be: red = 255, green = 255, blue = 255. For systems with more color depth the resulting inputs would be increased accordingly to the maximum value possible. Black is accomplished by setting the Red, Green and Blue to 0,0,0. The measurement of the black full screen is particularly susceptible to the effects of ambient lighting and room reflections.

The difference between the luminance of full screen white and that of full screen black gives us the luminance range of the display. This is important if the display is to be used in both day and nighttime conditions. The luminance range also limits the number of discriminable gray shades that the display can produce. This is particularly important for display of continuous tone imagery.

The full screen white and black luminance values are also used to calculate the Contrast Ratio of the Full Screen. This contrast ratio is expressed mathematically by the equation: $C = L_W / L_B$ where C is the contrast ratio, L_W is the luminance of the full screen white measurement and L_B is the luminance of the full screen black measurement. Display contrast is important for legibility, particularly of high spatial frequency information such as alphanumerics.

Grey Scale and Display Gamma

Eight or more full screen grey values are displayed and their luminance measured. The input values for the grey levels are equally spaced between the input value that displays the minimum luminance (black, zero) and the input value that displays the maximum luminance (white, maximum). These measurements allow the relationship between input value

and output luminance to be established. This relationship is called the gamma of the display. Also shown in the figure are the effects of filtering the display with either a night vision compatibility filter or a neutral density filter.

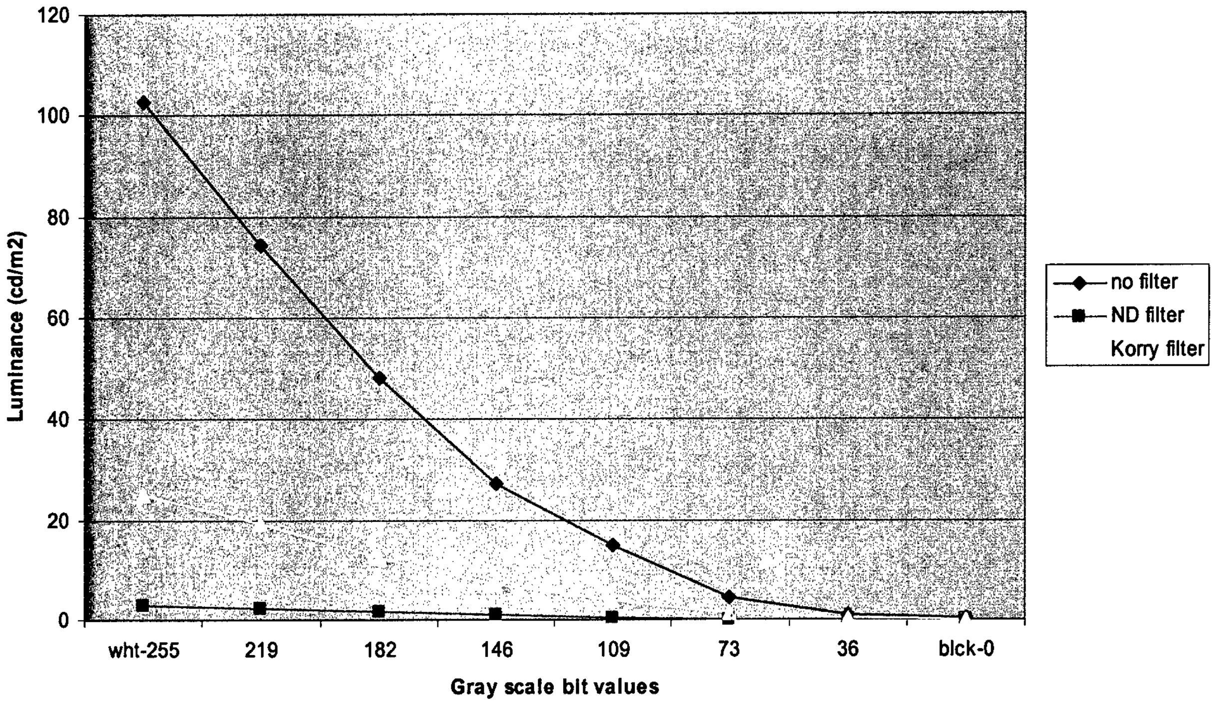

Figure 3. Gamma of a laptop computer liquid crystal display (LCD).

At low luminances, small changes in luminance are detectable by the human eye. However, as luminance increases, larger steps in luminance are required in order for the eye to discern the differences. Therefore, for most applications, it is desirable that the display gamma increase by small steps at low luminances and by increasingly larger steps as luminance increases.

Display Color Gamut

The color gamut of a display describes in CIE space the range of colors that the display can produce. Figure 4a shows CIE 1976 space. It illustrates the shape of CIE 1976 space and the color produced at any x,y point within the space. This is essentially the range of colors that a human can perceive.

Three color measurements are necessary to determine a display's gamut. Red is measured at maximum output with Green and Blue set to zero. That gives the triangle vertex in the red in Figure 2b. Then Green is measured at maximum output with Red and Blue set to zero. That gives the triangle vertex in the green. Finally, Blue is measured at maximum output with Red and Green set to zero. That gives the triangle vertex in the blue. Straight lines are drawn between vertices (Green, Red), (Green, Blue) and (Blue, Red) to form the triangle that defines the display color gamut. Figure 4b illustrates the result of a gamut measurement on an example monitor. The monitor can produce only the range of colors shown in the color triangle, a subset of what a human can perceive.

The color of the display white and black is generally measured along with the color gamut. The color of the white and black screen is reported as an x,y pair in CIE space.

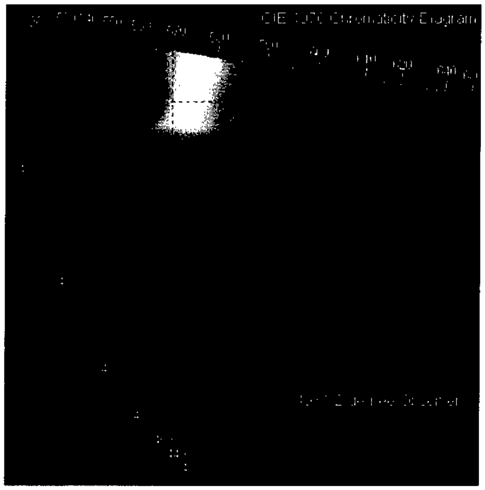

Figure 4a. Full spectrum of color visible to the human eye.

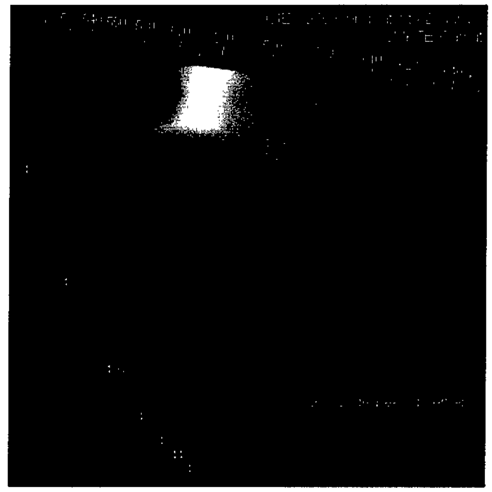

Figure 4b. Measured color gamut of a display

Uniformity of Color and Luminance

Uniformity of color and luminance refers to the variability that exists across the area of a full-screen display when, in theory, different areas of the display should have identical color and luminance characteristics. Measurements are made at specific points on the full screen white display to determine how much luminance and color variation is present in a full screen white display. The display format shown in Figure 5 is used as an alignment guide. Typically, either five (four corners and center) or nine (four corners, center, and midpoint of top, bottom and each side of the display) points are measured. The deviations for luminance are reported as a percentage difference from the maximum white measured. Color differences are reported in terms of u' v' differences. The same procedure is followed for each of the red, green, and blue display primaries.

Full screen black is measured at the same points, thus giving not only the uniformity of the black screen but also enabling us to compute contrast ratio at each point and evaluate the uniformity of contrast ratio.

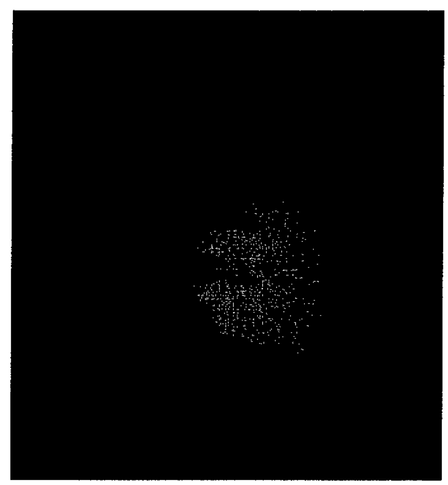

Figure 5. Alignment guide for display uniformity measurements.

Color and luminance uniformity contribute to making the display aesthetically pleasing. However, it is also very important if the display format employs color or brightness coding. A red symbol should look the same no matter where on the display it appears.

Viewing Angle Effects upon Color and Contrast

Viewing angle measurements are made to assess what happens when a display is viewed at angles other than the standard straight on perpendicular viewing condition. The same area of the display is measured, while the angle between the measuring device and the display is changed. Typically, the center of the display is measured. Either the display or the measuring device is rotated and repositioned to assure that the same area of the screen is being measured. It is important to measure the same area of the display to assure that spatial inhomogeneity does not contaminate the measurements. White luminance, black luminance and chromaticity coordinates are measured to assess the changes in luminance, contrast ratio or color that may come about as an effect of viewing angle. Viewing angles of +/- 30 degrees horizontal and +/- 15 degrees vertical are generally measured as a check of a manufacturer's viewing angle performance specification; however the selection of what viewing angle to assess can be driven by a particular application. For some displays, contrast will decrease significantly with increased viewing angle. Changes in color may also occur with increased viewing angle.

Ambient Illumination Effects upon Contrast

This is simply a matter of measuring display contrast in the same lighting environment in which the display will be used. Ambient illumination which strikes the surface of the display may be reflected back to the viewer's eye, thus reducing the perceived contrast of the display.

Checkerboard Luminance and Contrast

Displaying a checkerboard of white and black squares on the display and measuring the luminance of the squares gives us luminance and contrast data for the display as it would typically be used (i.e., with light and dark areas rather than all white or all black). A checkerboard pattern is presented on the display that is being measured. The size of the individual squares is determined by the size of the area that the light measuring device samples. The 500 pixel minimum should be maintained during this measurement. The measurement area of the measuring device should fit easily within a white or black square to assure that only the desired area is being measured. A cone-shaped device, called a fustrum, (shown in Figure 6) is used to block out any stray light from the surrounding display area. Measurements are made in the center of the display for both the white and black squares. This is made easy by creating a reverse pattern and displaying one of the patterns to measure the white square and then displaying the other pattern, which is the "negative" of the first, to measure the black square. If this is not possible, it is permissible to move the display or monitor to measure the squares, while remaining as close as possible to the center of the display. Checkerboard patterns should contain an equal number of black and white squares. Additional measurements at other positions on the screen using the checkerboard pattern will allow the consistency of contrast levels produced at these positions to be evaluated. The luminance is recorded and the contrast is computed in the same manner as it was done for full screen white and black.

Figure 6. Checkerboard contrast measurement set-up using fustrum to block stray light.

Response Time

Pixel response time measures how quickly a pixel can turn off or turn on. Slow pixel response times result in a blurring of motion sequences. Response time measurements require a measurement device with linear temporal characteristics

and a response time at least ten times shorter than the expected pixel response time of the display being measured. Typically, the output of the measuring device is connected to a storage oscilloscope for evaluation. The exact level at which a pixel is considered to be "on" or "off" is somewhat subjective and application driven. The shape of the excitation/extinction curve drives this criterion. When changing from black to white, 90 percent is often considered full on. When changing from white to black 10 percent is often considered full off. Remember that this measurement assesses the speed of the entire system (computer, drive electronics, etc.) and not just the response of the display elements. Also remember that the shape of the "pixel on" portion of the response curve is not just a mirror image of the "pixel off" portion of the response curve. This means that both on and off portions of the response curve must be measured and not extrapolated one from the other. Figure 7 shows example plots of typical pixel rise and fall times.

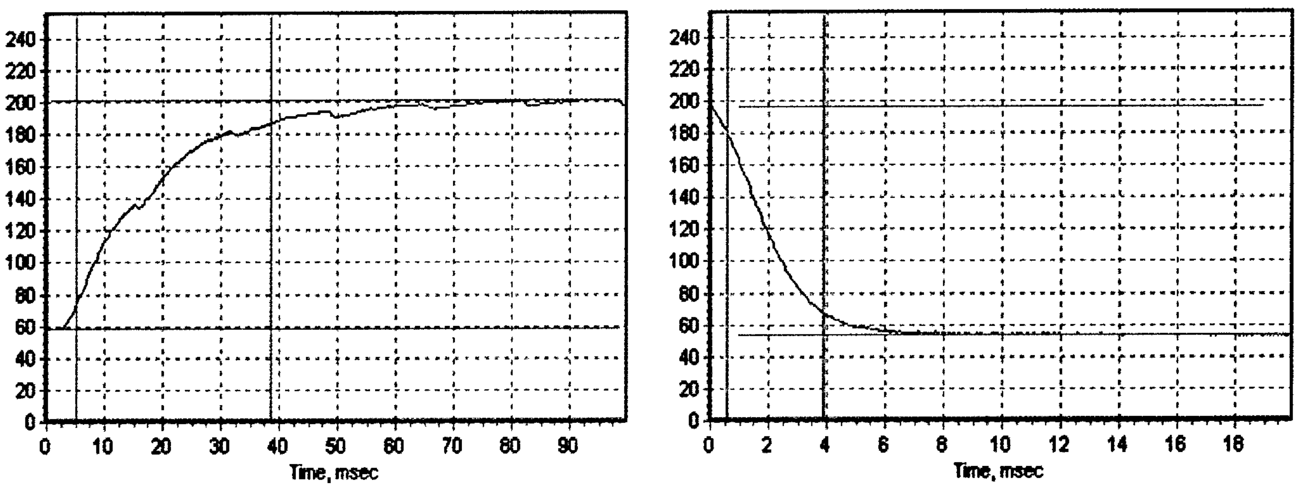

Figure 10. Example plots of pixel rise (left) and fall (right) times.

Power Consumption

Power consumption measurements are useful when displays are used in remote locations or where a limited amount of electricity is available to power the required equipment. Power consumption measurements should be made for the worst case, where the display is adjusted in a manner that the maximum possible power consumption occurs. In cases where this is atypical and where typical settings are available and achievable, power consumption measurements can be made at those settings or conditions.

Sunlight Readability

The evaluation of a display panel to determine its hi-ambient legibility involves evaluating how well it maintains good contrast in lighting conditions typical for where the display will be used. The human eye adjusts its aperture (pupil) size depending on the ambient lighting. This can restrict the amount of light from a display. If the display luminance is not high enough and the display contrast is too low the images on the display will not be legible, at least not rapidly legible.

Figure 11 illustrates the effects of direct sunlight. The critical requirement for good display legibility in HI-AMBIENT (sunlight) is a combination of screen reflectivity and luminance level where both impact contrast.

MIL-HDBK-87213: Provides guidance to assure display legibility in the most critical ambient illumination conditions. A Hoffman LM-33-52 sunlight contrast measurement system is used for this test. The setup consists of the following: a 107 klx (10 kfc) direct illumination source (projection source) normal to the center of the screen, a diffuse source of 7160 cd/m^2 (2055 fL) at 30° from the right of the screen, and the photometer 30° to the left of the screen.

SAE: J1757 Vehicular Display Metrology: Provides guidance using typical laboratory optical measuring equipment to configure representative light sources. The objective is to simulate the necessary conditions to determine the display's contrast compliance for minimum contrast within a viewing cone for worst case ambient conditions.

Figure 11. Display in normal office lighting (left) and in direct sunlight (right)

Night Vision Imaging System (NVIS) Compatibility

With increasing use of Night Vision Goggles (NVGs) in aircraft cockpits, care must be taken to assure that cockpit displays do not interfere with the NVGs. NVGs are particularly sensitive to wavelengths greater than 570 nm. MIL-STD-3009 defines the radiant energy interface requirements and test procedures applicable to NVIS compatible lighting systems for new or modified aircraft lighting equipment and crew stations. To determine NVIS compatibility, display radiance output as a function of wavelength is measured using a spectral scanning radiometer. NVIS compatibility is calculated from the spectral scan using the radiometer's software. Figure 12 shows spectral scans of a laptop computer display with and without two filters – a neutral density filter and an NVIS compatible filter.

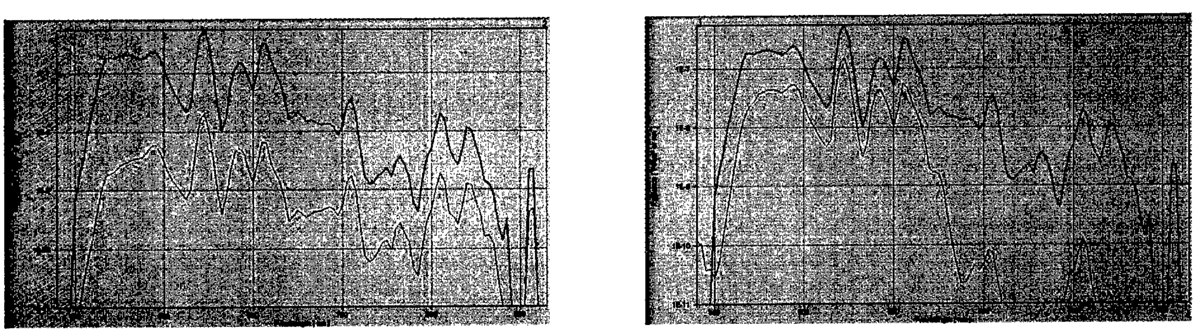

Figure 12. Spectral scans of a laptop computer display with and without a neutral density filter (left – not NVIS compatible) and with NVIS compatible filter (right).

Figure 13 illustrates the effects of the non filtered and filtered display upon NVGs. The image at the left shows the view through an NVG of a resolution chart with an NVIS compatible filtered display. The image on the right is the same view with the filter removed from the display. The radiant energy from the unfiltered display causes the automatic gain control of the NVG to decrease the NVG gain, thus leaving the resolution chart invisible.

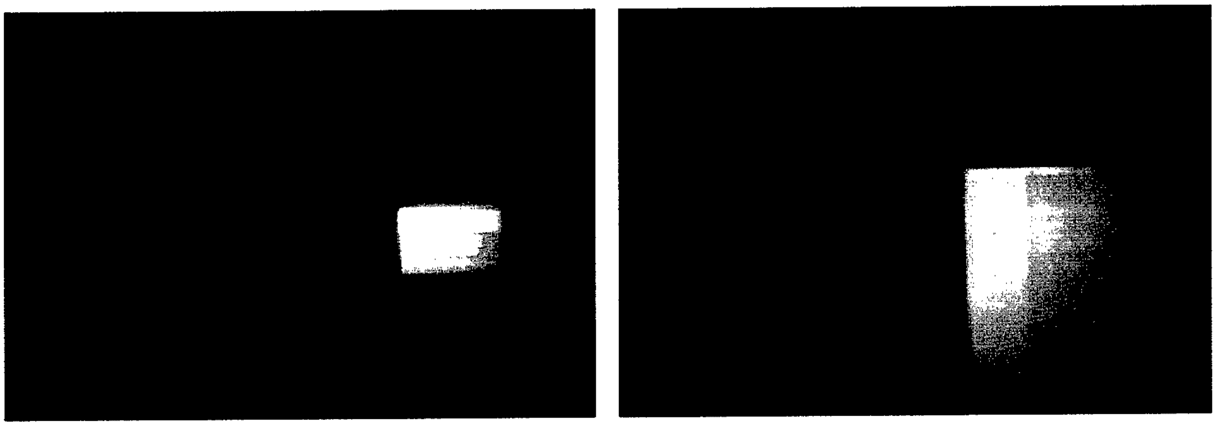

Figure 13. View through NVG of a paper resolution chart behind a display with NVIS compatible filter (left) and same view with filter removed from display (right).

SUMMARY

The Air Force Research Laboratory's Display Characterization Facility supports a variety of research projects in the areas of display hardware development, human visual perception and information presentation. The objective of this research is to maximize operator acquisition of visual information and facilitate decision-making through optimization of display parameters and design of display formats. A systems-engineering approach is required, taking into account the display performance parameters, operator visual system capabilities and limitations as well as information processing strategies and capabilities and environmental factors. Reliable objective measures of display performance parameters are a critical first step in optimizing operator performance.

Information presentation technologies available now and in the near future will have the potential for supporting battlespace visualization with multisensory information interfaces and virtual collaboration environments. However, human factors guidelines will be needed for determining the combination of information presentation technologies most appropriate for a particular operational environment and optimizing information presentation.

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